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RESEARCH ARTICLE

Organic farming and semi-natural habitats for multifunctional agriculture: A case study in hedgerow landscapes of Brittany

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Abstract

1. Finding more sustainable ways to produce food is a major challenge for humanity in the face of biodiversity extinction and climate change. Consequently, research on the ability of agroecosystems to provide multiple functions is growing. In this regard, the relative importance of organic farming and landscape-scale measures for improving multifunctionality has recently been debated.
2. We investigated the effects of farming system (conventional vs. organic) at field scale, total length of hedgerows in the landscape and their interaction on the multifunctionality of 40 winter cereal fields in Brittany (France). Our multifunctionality assessment integrated 21 indicators of five agroecosystem goods: biodiversity conservation, nutrient cycling and soil structure, pest and disease regulation, food production and socio-economic performance.
3. Many indicators of biodiversity conservation, pest and disease regulation, and socio-economic performance were higher in organic than in conventional systems. However, indicators of nutrient cycling and soil structure did not improve and food production was much lower in organic systems. Total hedgerow length in the landscape had less influence than organic farming on indicators, although we observed positive interactions. Granivorous carabid abundance and semi-net margin were highest in organic fields located in well-preserved hedgerow landscapes.
4. *Synthesis and applications.* Our study suggests that field-scale organic farming is necessary to promote biodiversity conservation and associated ecological functioning in crop fields, whereas landscape-scale preservation of semi-natural habitats alone is likely insufficient. Preservation of hedgerows in the landscape brings

additional ecological and socio-economic benefits for organic systems without compromising agricultural production. More broadly, our results call for more ambitious research into the myriad possible combinations of farming practices and agri-environmental measures at both field and landscape scales, to improve both below-ground and above-ground functioning.

KEYWORDS
Above-ground–below-ground functioning, agroecology, biodiversity conservation, ecological intensification, ecosystem service, natural enemy, profitability, yield

1 | INTRODUCTION

Given the major negative impacts of chemical agriculture and landscape simplification on biodiversity, climate and human health, it is urgent to make agricultural production more sustainable (Altieri & Nicholls, 2020). Crop fields and agricultural landscapes must promote biodiversity conservation and associated functions/services, including ecological regulation (e.g. predation, pollination), carbon sequestration, water quality maintenance and soil health protection. However, direct assessment of agroecosystem (AES) multifunctionality—simultaneously including agronomic, ecological and socio-economic aspects and quantifying both below-ground and above-ground functioning—remains scarce (Hölting et al., 2019; Le Provost et al., 2021). A better understanding of trade-offs and synergies between a wide range of taxa and functions would greatly inform the transition toward multifunctional agriculture.

Recently, there has been an interesting discussion on the importance of organic farming (or reducing agrochemical use) and landscape-scale measures (notably preserving semi-natural habitats) for reconciling biodiversity conservation and agricultural production (Brühl et al., 2022; Marrec et al., 2022; Stein-Bachinger et al., 2022; Tscharntke et al., 2021, 2022a, 2022b). As part of the European Green Deal, the Sustainable Use of Pesticides Regulation (SUR) and the Nature Restoration Law (NRL) have also been the subject of intense debate (Pe'er et al., 2023). Organic farming generally promotes biodiversity conservation and ecological functions in crop fields (e.g. Couthouis et al., 2023; Ostandie et al., 2022; Wittwer et al., 2021), although increased reliance on tillage to control weeds can undermine below-ground functioning (Tamburini et al., 2016). Furthermore, organic systems are often less productive than conventional systems, but not necessarily less profitable owing to higher subsidies or lower costs (Batáry et al., 2017; Couthouis et al., 2023; Wittwer et al., 2021). In addition to local farming systems and practices, landscape-scale measures generally consist in preserving or increasing landscape compositional or configurational heterogeneity, to increase species pools in the landscape and promote the dispersal of beneficial organisms into crop fields (Priyadarshana et al., 2024). In agricultural landscapes, semi-natural habitats such as hedgerows are more stable than cropped habitats, provide perennial refuges and trophic resources for a wide range of taxa, and ensure habitat connectivity (Dover, 2019). Hedgerows are part of the European Union Biodiversity Strategy for 2030 (European Commission, 2021), given their potential to improve below-ground and above-ground functioning, and delivering supporting, regulating, and provisioning services in agricultural landscapes (Montgomery et al., 2020; Staley et al., 2023).

Beyond their respective contribution, very few studies have considered interactions between field- and landscape-scale measures and their impacts on multifunctionality (Gebhardt et al., 2023; Smith et al., 2020). The effectiveness of local agri-environment schemes such as organic farming in promoting biodiversity and associated functions may depend on the composition and configuration of semi-natural habitats in the landscape (Concepción et al., 2008). Vice versa, landscape-scale measures (such as preserving hedgerow networks) may have different effects on biodiversity and functions depending on local farming systems and management practices. For example, frequent agrochemical disturbances might undermine the beneficial effects of landscape-scale measures (antagonistic effect) by preventing or limiting the spillover and population growth of beneficial organisms in fields under conventional farming (Madin & Nelson, 2023). Conversely, landscape-scale measures and associated processes such as spillover might have stronger beneficial effects in conventional fields (compensation effect) given their low levels of biodiversity (Roschewitz et al., 2005).

In this work, we investigate the effects of organic farming at field scale, total length of hedgerow networks in the landscape and their interaction on the multifunctionality of 40 winter cereal fields. Our quantitative multifunctionality assessment integrates 21 indicators of five AES goods: biodiversity conservation, nutrient cycling and soil structure, pest and disease regulation, food production and socio-economic performance (Figure 1). We assess the following hypotheses:

1. At field scale, organic farming is more multifunctional than conventional farming, with improved biodiversity conservation and pest and disease regulation, although we expect a trade-off with nutrient cycling and soil structure and food production (but not necessarily with socio-economic performance).
2. At landscape scale, crop fields in landscapes with higher total hedgerow length are more multifunctional, with beneficial effects on biodiversity conservation, nutrient cycling and soil structure, and pest and disease regulation (provision of habitats and spillover of beneficial organisms into crop fields), thus benefiting food production and socio-economic performance.

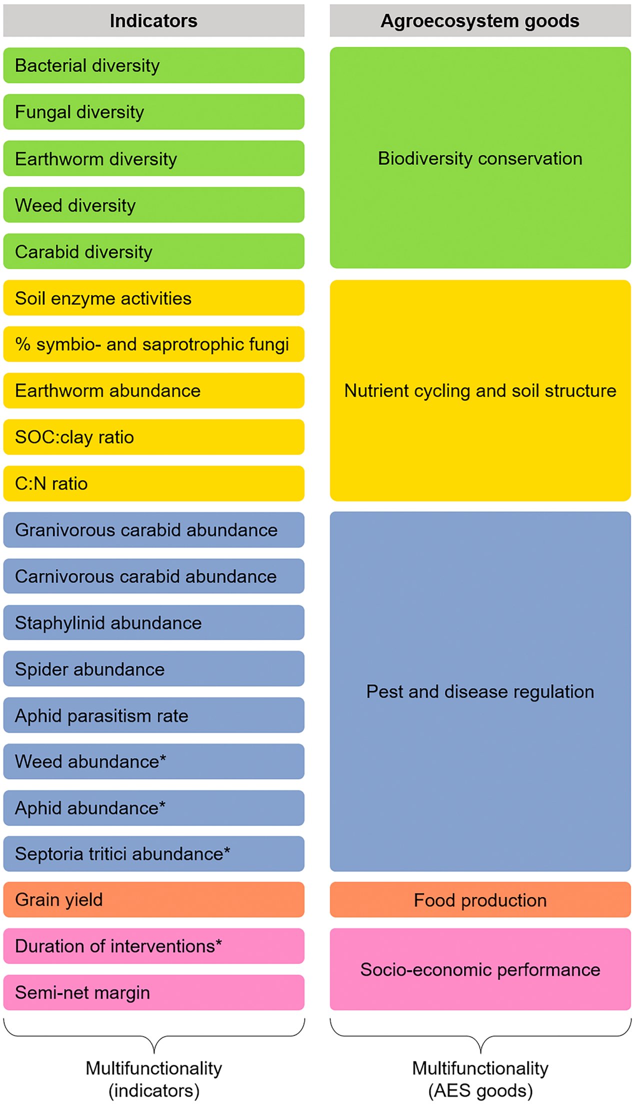

FIGURE 1 Sampled indicators and corresponding agroecosystem (AES) goods. Indicators are directly aggregated to compute multifunctionality giving equal weight to the 21 indicators. Alternatively, indicators are aggregated into their corresponding AES good, in turn aggregated to compute multifunctionality giving equal weight to the five AES goods. Indicators marked with an asterisk are inverted so that higher values indicate higher level of functionality or benefits.

3. However, strong filtering by agrochemical disturbances and low availability of natural resources in conventional fields may undermine these beneficial effects of hedgerow landscapes (antagonistic effect).

2 | MATERIALS AND METHODS

2.1 | Study site

We conducted the study in the southern part of the Zone Atelier Armorique, a Long-Term Socio-Ecological Research (LTSER) site in Brittany, France (47°59′35 N, 1°45′12 W). This region is characterized by dense hedgerow networks and crop-livestock farming systems (Figure S1). Hedgerows are mostly old (i.e. planted at least before World War II) and generally composed of oak *Quercus robur* L. or chestnut *Castanea sativa* Mill. trees planted on earth and stone banks and pruned for firewood every 9–12 years. When present, the shrub layer is generally dominated by hazel *Corylus avellana* L., hawthorn *Crataegus monogyna* Jacq., blackthorn *Prunus spinosa* L., spindle *Euonymus europaeus* L., broom *Cytisus scoparius* (L.) Link or gorse *Ulex europaeus* L. The climate is temperate oceanic, with around 715 mm of annual precipitation. The average annual temperature is around 12°C, with mild, wet winters averaging 7°C and moderately dry, hot summers averaging 18°C. We selected one pair of conventional and organic winter cereal fields in 20 landscape windows located along a gradient of total hedgerow length in the landscape, ranging from 6376 to 17,211 m (i.e. from 20 to 55 m/ha) within a buffer radius of 1 km (Figure S2). The 40 fields sampled included 36 wheat fields and 4 spelt fields. Organic farming fields have generally been managed this way for more than 20 years. Mean field size was 4.70 ± 2.96 ha and 2.89 ± 1.32 ha for conventional and organic fields, respectively. Average distance between two nearest fields was 588 ± 272 m, with a minimal distance of 124 m. Organic systems were characterized by the absence of any pesticide treatment (synthetic or organic), lower and exclusively organic fertilization, but higher frequency of tillage operations compared with conventional systems. Maize-winter wheat is by far the most common crop rotation in conventional systems, whereas organic systems generally have more complex crop rotations including temporary grasslands. All farmers signed a written informed consent to participate in this study, granting permission to conduct the fieldwork and use the anonymized collected data for scientific publications. The study did not require ethical approval.

2.2 | Landscape context

We adopted a space-for-time substitution approach (Pickett, 1989), where we assume that the responses of biodiversity or other indicators to landscape changes in space vs. time are similar. Kermap (https://kermap.com/en/) generated hedgerow mapping, via computer-assisted photointerpretation based on the National Institute of Geographic and Forest Information orthophotograph of 2017. We computed the total length of hedgerows within circular buffer radii of 250, 500, 750, and 1000 m around each field centre using Chloe software (Boussard & Baudry, 2017). Regardless of the buffer scale, we did not find strong correlations between total hedgerow length and other metrics known to affect biodiversity, such as the size of sampled fields (t-tests: $|r| < 0.27$, $p > 0.089$), percentage of semi-natural habitats excluding hedgerows (t-tests: $|r| < 0.30$, $p > 0.061$), crop diversity (t-tests: $|r| < 0.11$, $p > 0.508$) or organic farming cover (t-tests: $|r| < 0.33$, $p > 0.036$) in the landscape.

2.3 | Field data collection and indicators

Sampling was carried out between April and July 2019 in winter cereal fields. Samples were collected in crop fields at least 5 m away and up to 50m from field margins. Table S1 provides a summary of protocols, including the number of sessions, type and dimension of samples, and sampling design in crop fields. A detailed version of methods can be found in the Supporting Information. In each field, plant and invertebrate samples were summed (coverage, counts), and microorganism samples were averaged (relative abundances), before computing corresponding indicators (Figure 1), whose raw statistics are provided in Table S2.

Biodiversity conservation was estimated by the sequence cluster richness of bacteria and fungi, and the species richness of weeds and carabids (Figure 1).

Nutrient cycling and soil structure were estimated by soil enzyme activities (Cheviron et al., 2022), proportion of symbiotrophic and saprotrophic fungi (Creamer et al., 2022), earthworm abundance (Blouin et al., 2013), soil organic carbon:clay ratio (SOC:clay ratio) (Johannes et al., 2017), and organic carbon:nitrogen ratio (C:N) (Brust, 2019) (Figure 1). We considered 10 enzymes related to the cycling of phosphorus (phosphatase, alkaline phosphatase, phosphodiesterase), carbon (α-glucosidase, β-glucosidase, β-galactosidase), nitrogen (arylamidase, N-acetyl-glucosaminidase, urease), and sulphur (arylsulphatase). We discarded phosphodiesterase, α-glucosidase and urease, which were highly correlated with alkaline phosphatase (*t*-tests: $r > 0.70$; $p < 0.001$). Given the large number of enzymes, we aggregated their activities using an equivalent of Hill-Shannon diversity (${}^{q}M_{ef}$ index; Byrnes et al., 2023) that considers both the number of enzymes and their levels of activity (see further explanation in the following sub-section *Agroecosystem goods and multifunctionality*). We calculated the total proportion of symbiotrophic (including endophytes and mycorrhizae) and saprotrophic fungi in each sample, since many taxa are both symbiotrophic and saprotrophic. The proportions of pathogenic fungi and symbiotrophic, facilitating or competing bacteria were very low and therefore were not considered. Earthworms were largely represented by anecic and endogeic species. SOC:clay ratio was generally below the values of 1:8, which is considered to indicate good soil structural stability and quality (Johannes et al., 2017). C:N ratio was generally below the commonly recommended value of 10:1, considered to indicate a dynamic equilibrium condition that should be maintained in agricultural soils (USDA–NRCS, 2011).

Pest and disease regulation was estimated by the responses of both natural enemies and pests/diseases, to distinguish ecological processes related to the 'enemies' versus 'resource concentration' hypotheses (Root, 1973). Regarding natural enemies, we measured the activity-density (pitfall traps) of predominantly granivorous carabids, carnivorous carabids, staphylinids and spiders, and aphid parasitism rate (by parasitoid wasps) (Figure 1). Although predator abundance is not always correlated with predation intensity, we assume that increased abundance of different predator taxa reflects greater potential for biological regulation of a variety of pests and greater resilience to secondary pest outbreaks (Dainese et al., 2017). Information on the diet of carabid beetles (Table S3) was collected from BETSI (Hedde et al., 2012) and Carabids.org (Homburg et al., 2014) databases. Regarding pests and diseases, we measured the abundances of weeds (total coverage in quadrats), aphids (total number of individuals on cereal crops) and septoria (fraction of cereal leaves presenting disease symptoms) (Figure 1; Table S2).

Food production was estimated by field-scale grain yield (q ha^{-1}) provided by farmers during interviews (Figure 1).

Socio-economic performance was estimated by cumulative duration of operations and semi-net margin, considering all agricultural operations carried out between the harvest of the previous and current crops (including cover cropping, tillage operations, sowing, fertilization, and pesticide treatments) (Figure 1). The cumulative duration of interventions accounts for the type of equipment used for each operation (h ha^{-1}). Annual semi-net margin (€ ha^{-1}) was calculated by subtracting operating expenses (seeds and inputs) and equipment (depreciation, maintenance and fuel consumption) from the market price of winter wheat and spelt. This indicator reflects the economic viability of individual fields but does not consider subsidies or economy at the farm level. We used Agrosyst software (Jolys et al., 2016) to calculate these socio-economic indicators.

2.4 | Agroecosystem goods and multifunctionality

We used a recent approach based on Hill numbers (Byrnes et al., 2023) to estimate AES goods and multifunctionality indices (Figure 1). This approach is equivalent to the effective number of species (e.g. Hill-Shannon index) that considers both the number of species and their relative abundances to quantify species diversity. Similarly, multifunctionality indices consider not only the mean of indicators or AES goods but also the relative contribution of each indicator or AES good to the total level of functioning. We used the R function 'getMF_eff' from the 'multifunc' package (Byrnes, 2022) to calculate the index of 'Effective multifunctionality' (${}^{q}M_{ef}$)—instead of averaging indicators or AES goods as in previous approaches (Byrnes et al., 2014). We used a Hill number of order $q = 1$ that does not upweight high- or low-performing indicators or functions. 'Effective multifunctionality' is a measure of the cumulative performance of the system where all indicators or AES goods provide equally (Byrnes et al., 2023). First, for indicators whose lower values indicate higher levels of functionality or benefits (i.e. pest abundances and duration of interventions), we inverted variables using the formula $-x_i + \max(x_i)$ where x_i are the measures of variable *i*. Second, we *z*-standardized all indicators (with different units). Third, we aggregated indicators to compute the corresponding AES goods. Finally, multifunctionality was calculated in two ways: (1) aggregating the 21 *z*-standardized indicators, each equally contributing to the multifunctionality index, and (2) aggregating *z*-standardized AES goods so that they have equal weights.

2.5 | Statistical analysis

We used Gaussian linear models to analyse the effects of organic farming at field scale, total hedgerow length in the landscape and their interaction on the 21 indicators, five AES goods and two multifunctionality indices. Response variables and the continuous explanatory variable (total hedgerow length) were *z*-standardized to compare the importance of predictors across all response variables (Schielzeth, 2010).

Total hedgerow length was divided by two standard deviations (instead of one) for direct comparison with the categorical explanatory variable (organic farming) (Gelman, 2008). We followed the approach described by Ho et al. (2019) to better represent raw data and statistical information, and move beyond the binary vision associated with p-values and significance thresholds. We used a nonparametric bootstrapping approach (bias corrected and accelerated method with 5000 bootstrap samples) (Puth et al., 2015) to estimate confidence intervals of model parameter estimates (R package 'boot'; Canty & Ripley, 2024) and to compare means of indicators, AES goods, and multifunctionality indices between conventional and organic farming systems (so-called 'Gardner-Altman' plots, R package 'dabestr'; Ho et al., 2019). Bootstrapping avoids making any distributional assumption about population data outside of the observed sample, and provides more reliable confidence intervals than traditional approaches based on regression standard errors, especially for relatively small datasets with extreme values (Buisson, 2021). Analyses were performed for each buffer scale (radii of 250, 500, 750 and 1000 m around crop fields) separately.

3 | RESULTS

3.1 | Effects of organic farming at field scale

Organic farming had higher level of functionality than conventional farming for many indicators, notably those related to biodiversity conservation and pest and disease regulation (Figures 2 and 3; Table S4). Multifunctionality based on indicators therefore tended to be higher in organic farming systems (Figure 2; Table S4). However, organic farming also had higher level of weed abundance and lower level of food production, to the extent that multifunctionality based on AES goods was similar between organic and conventional farming.

3.2 | Effects of total hedgerow length in the landscape and interaction with the local farming system

Whatever spatial scale considered, total hedgerow length in the landscape had much less influence than local farming systems on indicators (Figure 2; Figures S3–S5; Tables S4–S7). However, we observed positive interactions between total hedgerow length and organic farming. Granivorous carabid abundance and semi-net margin were highest in organic fields located in landscape with higher total hedgerow length (Figures 2 and 4; Table S4), a result consistent across spatial scales (Figures S3–S5; Tables S5–S7). Carnivorous carabid and spider abundances also tended to increase in OF fields with higher total hedgerow length, although results did not reach statistical significance (Figure 2; Table S4). Food production (grain yield) did not vary much along the hedgerow landscape gradient but tended to increase in OF fields with higher total hedgerow length (Figure 4).

4 | DISCUSSION

Organic systems were not more multifunctional than conventional systems, despite the large increases in many indicators, especially those related to biodiversity conservation and pest and

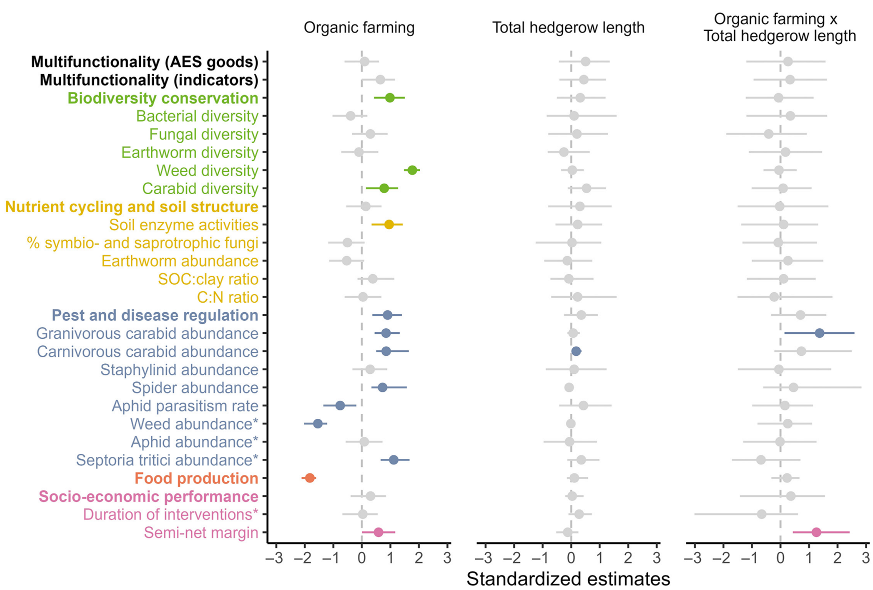

FIGURE 2 Standardized regression estimates (mean and 95% confidence interval based on bootstrap resampling) from linear models measuring relationships between environmental factors (organic farming, total hedgerow length, and their interaction) and response variables (multifunctionality, agroecosystem (AES) goods, and corresponding indicators). Non-significant effects are shown in grey (i.e. zero falls within the 95% confidence interval). Indicators marked with an asterisk are inverted so that higher values indicate higher level of functionality or benefits. For plotting purposes, we only show the results using a buffer radius of 1 km around crop fields, which provides a good summary of the most robust effects (whose estimates remain consistent between successive spatial scales). Full results are given in Figures S3–S5.

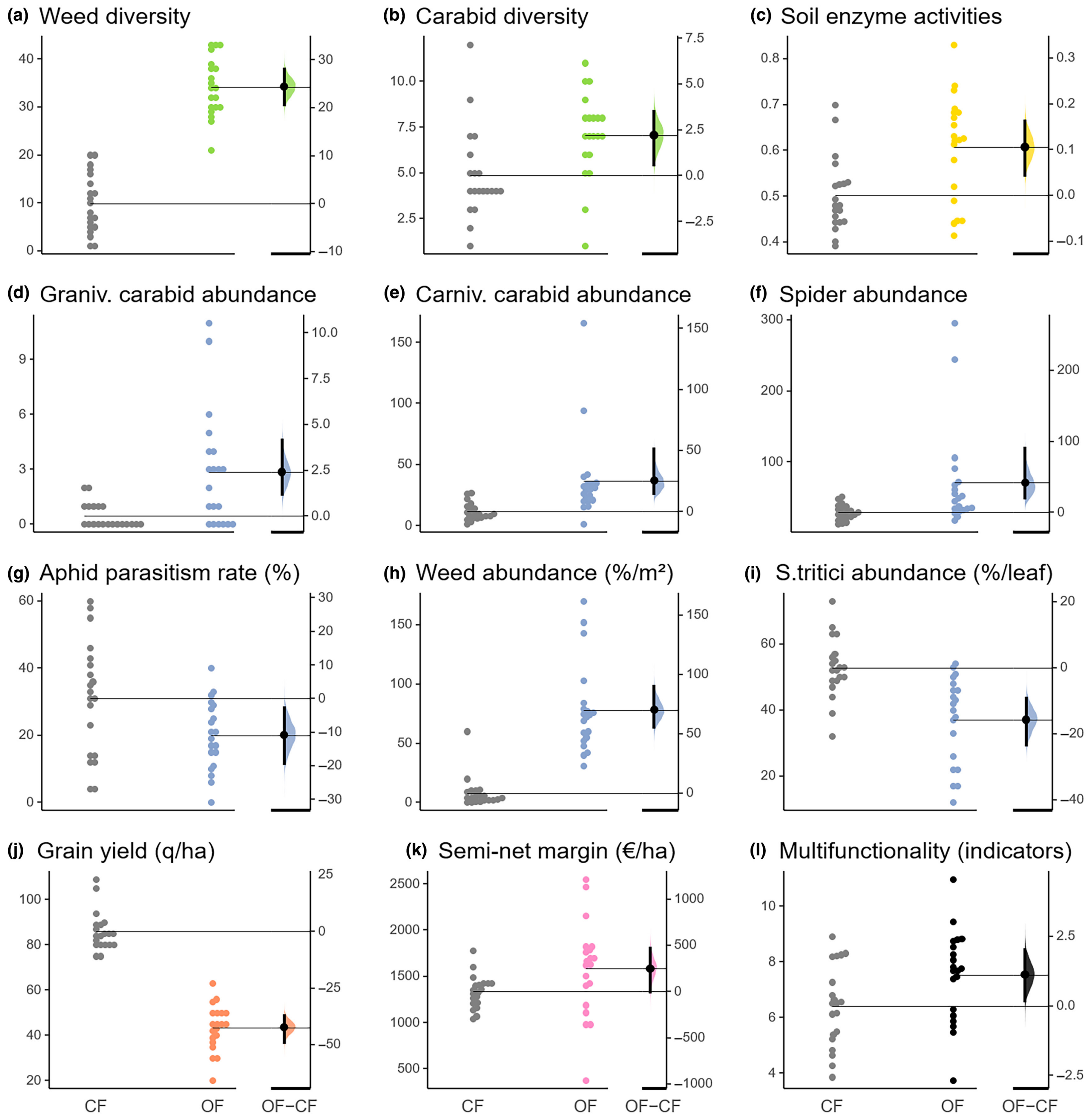

FIGURE 3 Gardner-Altman plots for indicators in conventional (CF) and organic (OF) farming systems. Each point is an observation whose raw value can be read on the left axis. Horizontal lines indicate the mean of indicators in CF and OF systems. The right axis indicates the effect size; here the mean difference of indicators between systems (mean OF − mean CF). The curve indicates the resampled distribution of mean difference based on bootstrapping. Points and vertical lines indicate the mean and 95% confidence interval of mean difference.

disease regulation (hypothesis 1). In particular, organic farming had much higher weed diversity (+24 species per field on average) and higher abundances of carnivorous carabids and spiders reaching extreme values in some cases (+26 and +42 individuals per pair of pitfall traps on average). However, we observed much lower food production (−42 $q\,ha^{-1}$ on average) in line with many studies (e.g. Couthouis et al., 2023; Gong et al., 2022; Ostandie et al., 2022; Wittwer et al., 2021). On the one hand, the absence or reduction of agrochemical disturbances in organic fields favours biodiversity, allowing the development of more abundant and diverse weed communities and associated taxa such as predators of crop pests (Diehl et al., 2012). On the other hand, higher weed competition in organic fields probably contributes significantly to yield reduction (Oerke, 2006), in addition to the lower fertilization and lower productivity of ancient cereal varieties in organic systems. Arable weeds certainly play a major role in the trade-off between biodiversity

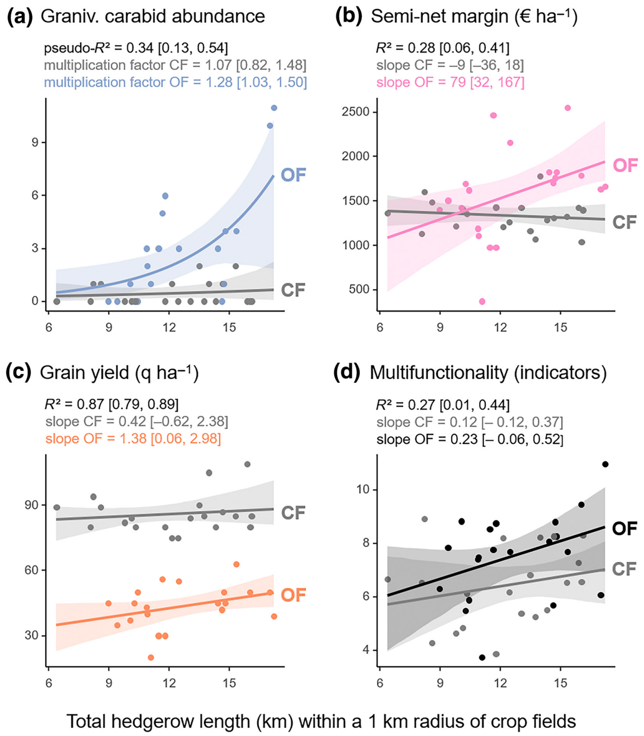

FIGURE 4 Regression plots describing the relationships between total hedgerow length within a 1 km radius of crop fields and (a) granivorous carabid abundance, (b) semi-net margin, (c) grain yield and (d) multifunctionality based on indicators, in conventional (CF) and organic (OF) farming systems. Each point is an observation. Shaded areas around regression curves, and numbers in brackets, indicate 95% confidence intervals based on bootstrap resampling. Regression plots are based on Gaussian linear models, except for granivorous carabid abundance (counts) for which a Poisson generalized linear model was used and McFadden's pseudo-R^2 (varying between 0 and 1) was calculated.

conservation and food production. More research is needed to find solutions that promote weed coexistence and reduce the dominance of most competitive species, which should significantly improve agroecological weed management (Adeux et al., 2019; Boinot, Alignier, & Storkey, 2024; MacLaren et al., 2020). Our results also underline the need to enhance below-ground functioning in organic systems, in contrast to previous studies (Birkhofer et al., 2008; Walder et al., 2023; Wittwer et al., 2021). Higher tillage frequency and ploughing to control weeds likely undermine below-ground functioning in organic systems (Tamburini et al., 2016), which may offset the benefits of pesticide-free farming (Hussain et al., 2009), organic amendments (Walder et al., 2023) and more complex rotations for soil biota (D'Acunto et al., 2018). Solutions may lie in the combination of specific practices at field scale such as reduced-tillage systems, crop diversification and crop-livestock systems to create more favourable conditions for soil biota and health (Toor et al., 2021) while limiting yield losses due to weed competition (Liebman & Gallandt, 1997; MacLaren et al., 2020).

Contrary to our expectations (hypothesis 2), total hedgerow length had lower influence than organic farming on indicators, AES goods and multifunctionality. However, we found evidence that conventional farming at field scale undermined some beneficial effects of total hedgerow length (through antagonistic effects; hypothesis 3). Granivorous carabid abundance and semi-net margin were highest in organic fields located in landscapes with dense hedgerow networks, a result consistent across spatial scales. Hedgerows provide major overwintering habitats and refuges for natural enemies of pests (Maudsley, 2000), but also ensure the spatiotemporal continuity of natural resources (Iuliano & Gratton, 2020) and habitat connectivity (Fischer et al., 2013) in agricultural landscapes. Complementarily, organic farming more likely promotes natural enemy dispersal and population growth into crop fields, due to reduced agrochemical disturbances and increased availability of natural resources, a key driver of movement and residence time of organisms in habitats (Corbett & Plant, 1993). In their reanalysis of the global database from Dainese et al. (2019), Madin and Nelson (2023) also found interaction effects, so that natural enemy activities were highest in organic fields located in landscapes with lower cropland cover. Most existing landscape studies are restricted to conventional farming, which is not conducive to ecological intensification (strong agrochemical disturbances, low crop diversity) and might be one of the main reasons why hedgerows and other semi-natural habitats do not always fulfil their expected functions in crop fields (Albrecht et al., 2020; Précigout & Robert, 2022).

Worldwide, landscape homogeneity is associated with decreased biodiversity-mediated benefits (natural regulation of pests, pollination of crops) and lower crop yields (Dainese et al., 2019), but few studies have assessed the influence of landscape context on profitability (Abson et al., 2013; Smith et al., 2020). For organic systems, we found a positive relationship between total hedgerow length in the landscape and semi-net margin, which cannot be explained by variations in the main farming practices and associated costs. Indeed, the number of tillage operations and fertilization rates in organic fields did not vary much with total hedgerow length (t-tests: $r=-0.13$, $p=0.590$ and $r=-0.28$, $p=0.235$, respectively). The increase in granivorous carabid abundance (×1.28 number of individuals per 1 km increase in hedgerow length), potentially contributing to reducing weed population growth and competition with crops (Carbonne et al., 2020; Daouti et al., 2022), may partly explain the increase in grain yields and annual semi-net margin (+1.38 q ha^{-1} and +79 € ha^{-1} per 1 km increase in hedgerow length). Hedgerows are also major habitats for more mobile taxa, such as many birds and small rodents that can contribute to the natural regulation of weeds and arthropod pests (Wolton, 2015), and flying insects that ensure the pollination of entomophilous crops (not considered in our study) (Morandin & Kremen, 2013). In addition, hedgerow landscapes may create favourable abiotic conditions for improving yields and profitability, for example by buffering wind, extreme temperatures and other climatic events (Forman & Baudry, 1984).

In conclusion, our study suggests that field-scale organic farming (or reduced agrochemical disturbances) is necessary to promote biodiversity conservation and associated ecological functioning in crop fields, whereas landscape-scale preservation of semi-natural habitats alone is likely insufficient. Preservation of hedgerows in the landscape brings additional ecological and socio-economic benefits for organic systems without increasing pest pressure or compromising agricultural production. Some may argue that a decrease in food production due to reduced agrochemical inputs and agricultural area would threaten food security. However, loss of agricultural area due to hedgerows is negligible (−2% considering the maximum total length of hedgerows observed in our study and assuming that hedgerows are 4 m wide). For organic farming, the positive relationship between total hedgerow length and grain yield could more than compensate for this loss of agricultural area (+51% increase in yield on average in denser hedgerow landscapes, assuming they are composed entirely of organic fields). Most importantly, we echo the major arguments from Holt-Giménez et al. (2012), Benton and Bailey (2019) and Pe'er et al. (2023): (1) hunger is caused by poverty and inequality rather than scarcity, (2) agricultural productivity has paradoxically promoted food system inefficiency (malnutrition, food waste) and (3) the greatest threats to food security are climate change, soil and landscape degradation/pollution, evolution of pesticide resistance, and losses of biodiversity and associated ecosystem services. Considering these threats, the stability of functioning and production is becoming an increasingly important property of agroecosystems. A growing body of evidence shows increased stability or resilience in pest control (Feit et al., 2021), pollination (Garibaldi et al., 2011), yields (Nelson et al., 2022; Redhead et al., 2020) and profitability (Abson et al., 2013) near semi-natural habitats or in more complex/diverse agricultural landscapes. Hedgerow landscapes may therefore promote the stability of agroecosystem functioning by favouring biodiversity, providing refugia and buffering extreme events, which requires further research and longer-term experimentation.

AUTHOR CONTRIBUTIONS

Cendrine Mony and Audrey Alignier designed and led the study. Stéphanie Aviron, Colette Bertrand, Nathalie Cheviron, Gwendoline Comment, Emma Jeavons, Cécile Le Lann, Samuel Mondy, Christian Mougin, Pierre-Antoine Précigout, Claire Ricono, Corinne Robert and Philippe Vandenkoornhuyse contributed to data collection. Grégoire Saias and Sébastien Boinot contributed to data curation. Sébastien Boinot analysed the data and led the writing of the manuscript. All authors contributed substantially to revisions.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data available via the Dryad Digital Repository: https://doi.org/10.5061/dryad.x69p8czrg (Boinot, Alignier, Aviron, et al., 2024).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1: Questionnaire.

Figure S1: Bocage landscape and diversity of hedgerows in the Zone Atelier Armorique, a Long-Term Socio-Ecological Research (LTSER) site in Brittany, France.

Figure S2: Crop fields ($n = 40$) in the southern part of the Zone Atelier Armorique, Brittany, France.

Figure S3: Standardized regression estimates (mean and 95% confidence interval based on bootstrap resampling) from linear models measuring relationships between environmental factors (organic farming, total hedgerow length within a 750 m radius of crop fields, and their interaction) and response variables (multifunctionality, agroecosystem (AES) goods, and corresponding indicators).

Figure S4: Standardized regression estimates (mean and 95% confidence interval based on bootstrap resampling) from linear models measuring relationships between environmental factors (organic farming, total hedgerow length within a 500 m radius of crop fields, and their interaction) and response variables (multifunctionality, agroecosystem (AES) goods, and corresponding indicators).

Figure S5: Standardized regression estimates (mean and 95% confidence interval based on bootstrap resampling) from linear models measuring relationships between environmental factors (organic farming, total hedgerow length within a 250 m radius of crop fields, and their interaction) and response variables (multifunctionality, agroecosystem (AES) goods, and corresponding indicators).

Table S1: Overview of field data collection and sampling methods for each taxon.

Table S2: Raw statistics of indicators.

Table S3: Diet of carabid species.

Table S4: Results of Gaussian linear models assessing the effects of organic farming, total hedgerow length within a 1 km radius of crop fields, and their interaction, on indicators, agroecosystem goods, and multifunctionality.

Table S5: Results of Gaussian linear models assessing the effects of organic farming, total hedgerow length within a 750 m radius of crop fields, and their interaction, on indicators, agroecosystem goods, and multifunctionality.

Table S6: Results of Gaussian linear models assessing the effects of organic farming, total hedgerow length within a 500 m radius of crop fields, and their interaction, on indicators, agroecosystem goods, and multifunctionality.

Table S7: Results of Gaussian linear models assessing the effects of organic farming, total hedgerow length within a 250 m radius of crop fields, and their interaction, on indicators, agroecosystem goods, and multifunctionality.

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